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FROM: PROI (TI) (STINFO) 16 Jun 2000

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-TP-2000-134**
Miller, Timothy, "Effects of Damage on Interfacial Crack Tip Fields"

International Conference for Computational Engineering Science (Statement A)
(Los Angeles, CA, 21-25 Aug 2000) (Submission Deadline: 1 Aug 2000)

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LESLIE. S. PERKINS, Ph.D (Date)
Staff Scientist
Propulsion Directorate

Effects of Damage on Interfacial Crack Tip Fields

T. C. Miller

Air Force Research Laboratory

Edwards Air Force Base, California

International Conference on Computational Engineering Science

Los Angeles, California

August 21-25, 2000

Approved for Public Release; Distribution Unlimited

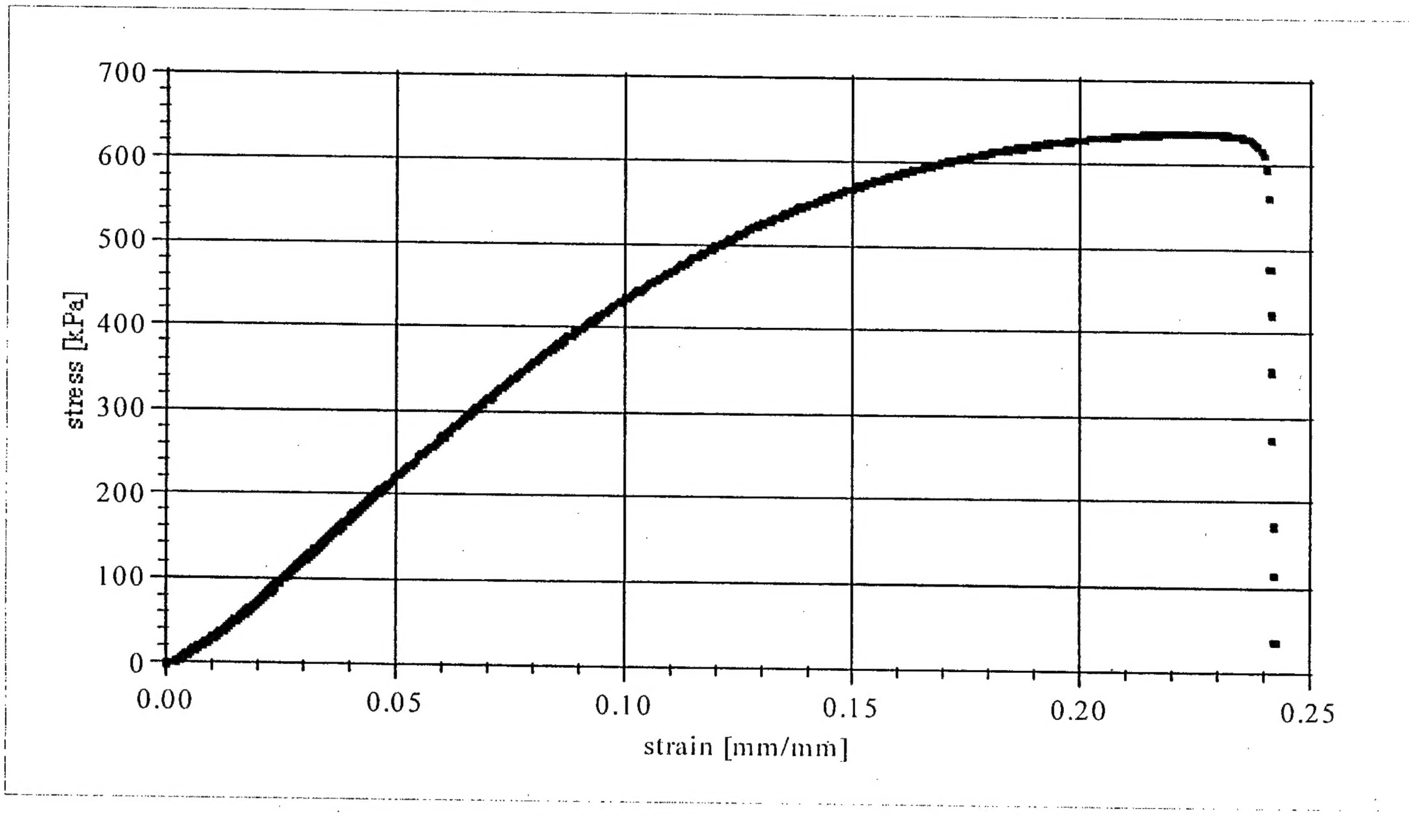
Background

- Introduction -- What situation are we interested in?
- Motivation -- Why is damage near the crack tip important to us?

Introduction - Material Description

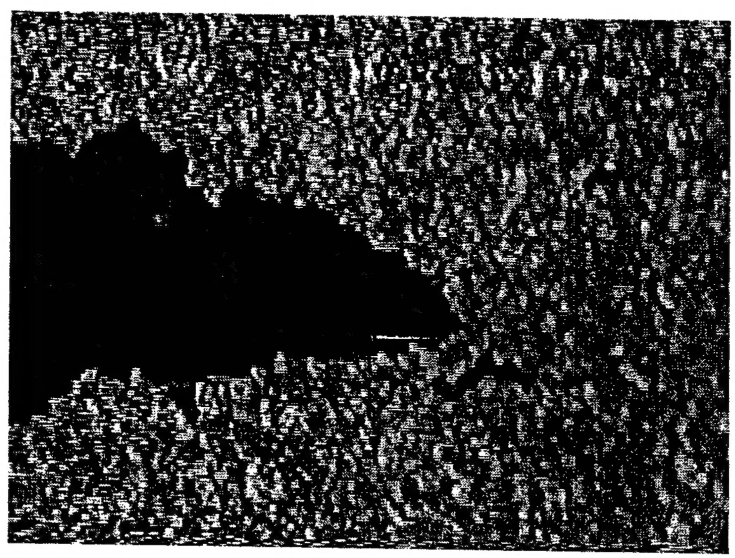
- Materials involved are rubbery particulate composites
- Hard particles are embedded in a (relatively weak) rubber matrix

remove extra space.



Introduction - Damage Description

- Under applied stress, damage occurs by separation of the matrix from the hard particles
- Damage can occur during processing, transportation, and storage
- After the damage event, removal of stresses may conceal this type of damage
- The size and extent of damage may be difficult to assess



Motivation

- Damage can determine whether a nearby crack grows, and, if so, how it grows (both trajectory and speed)
- Cracks can promote uneven burning and can alter propulsion behavior, resulting in inaccurate delivery of payload
- Catastrophic destruction of both rocket and payload is possible
- Collateral damage to surrounding equipment and personnel is also possible

Details of the Analysis

- Parameters examined in this study
- Analysis methods

Parameters Examined

- Size of damage zones was varied
- Load angle was varied
- Damage was located in each of the two materials

Variables considered in the analysis

Damage zone sizes considered	Rectangular damage zones with edge lengths of 0.000 (undamaged), 3.175, 6.350, and 12.700 mm
Location of damage zone	Damage near interface in both materials 1 and 2 considered
Loading angle ω	0°, 30°, 60°, 90°

Semi-Energetic Method

- Semi-energetic method is really just a combination of two methods
- Domain integral method is used to determine J
  - (Any other reliable method of determining J would also be acceptable)
  - Advantage: J is easy to determine this way and is robust with respect to mesh design
- J is converted to |K'|
- Crack flank displacements are used to find both magnitude and phase angle of K' as function of r

Semi-Energetic Method - Equations Used in Semi-Energetic Method

$$(\sigma_{yy} + i\sigma_{xy})_{\theta=0} = \frac{\vec{K}'\left(\frac{r}{h}\right)^{i\epsilon}}{\sqrt{2\pi r}} \tag{1}$$

$$\vec{\delta} = \delta_y + i\delta_x = (u_y + iu_x)_{\theta=\pi} - (u_y + iu_x)_{\theta=-\pi} \tag{2}$$

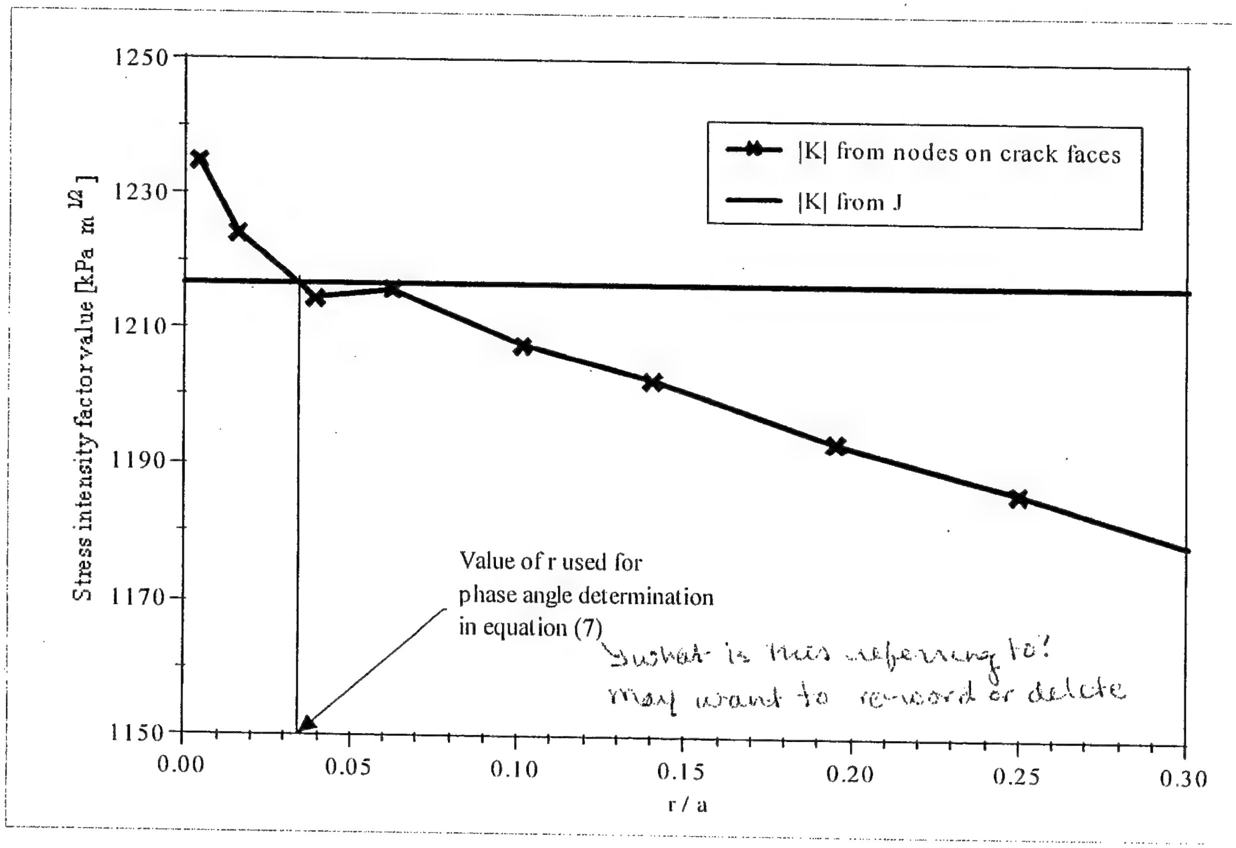
$$|\vec{K}'| = \frac{\sqrt{2\pi(1+4i\epsilon)}|\vec{\delta}|E^* \cosh(\pi\epsilon)}{8\sqrt{h}\sqrt{r/h}} \tag{3}$$

$$\psi' = \phi - \epsilon \ln\left(\frac{r}{h}\right) + \beta \tag{4}$$

$$|\vec{K}'| = \sqrt{JE^*} \tag{5}$$

Semi-Energetic Method - Phase Angle Determination

- An appropriate value of r is chosen so that the two methods of finding magnitude of K agree
- This value of r is used as basis of phase angle determination

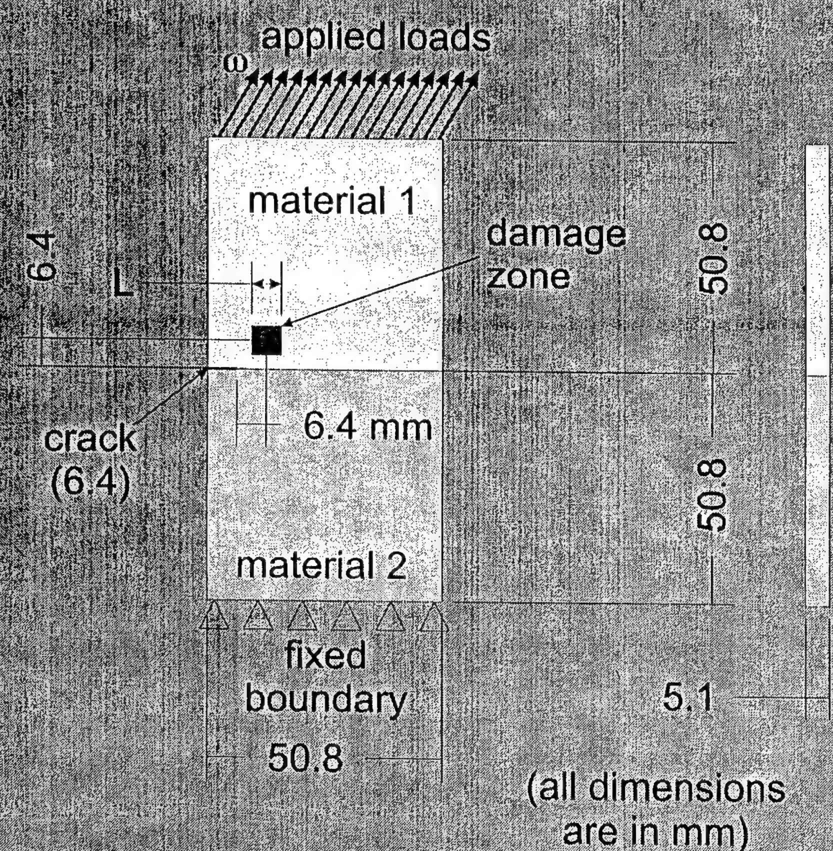


Geometry and Boundary Conditions

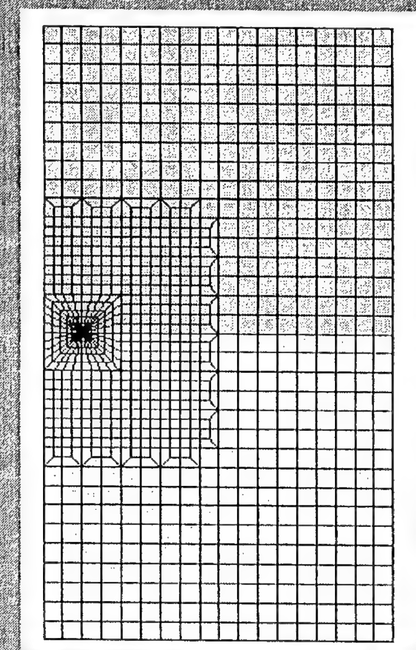
- Bottom of specimen was fixed, and tractions were varied on top surface
- Specimens were identical except for location and size of damage zone
- Damage was allowed in both top and bottom materials
- Damage was modeled by using a smaller value for Young's modulus:

Material	Young's Modulus [kPa]	Poisson's ratio
Material 1	2784	0.5
Material 2	5568	0.5
Damaged Material	696	0.5

Geometry and Boundary Conditions - Overall Specimen

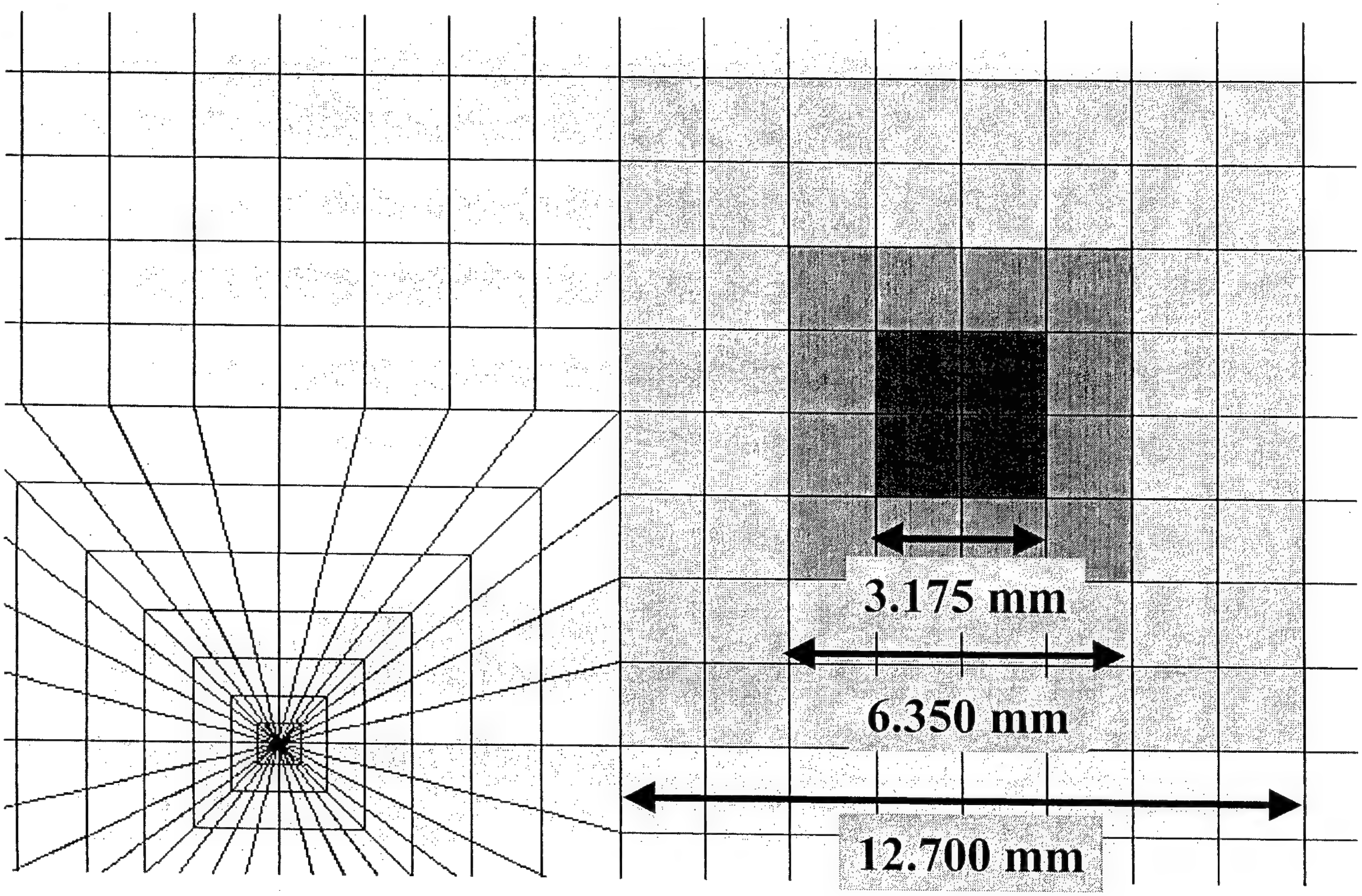


Geometry and Boundary Conditions



Mesh Used to Model Specimen

Geometry and Boundary Conditions - Damaged Regions



Modeling of Damaged Regions

Finite Element Modeling

- Near the tip, degenerate quadrilateral elements were used
- Graded mesh near the tip
- The modeling of incompressible materials required hybrid elements were used to prevent ill-conditioning

Results

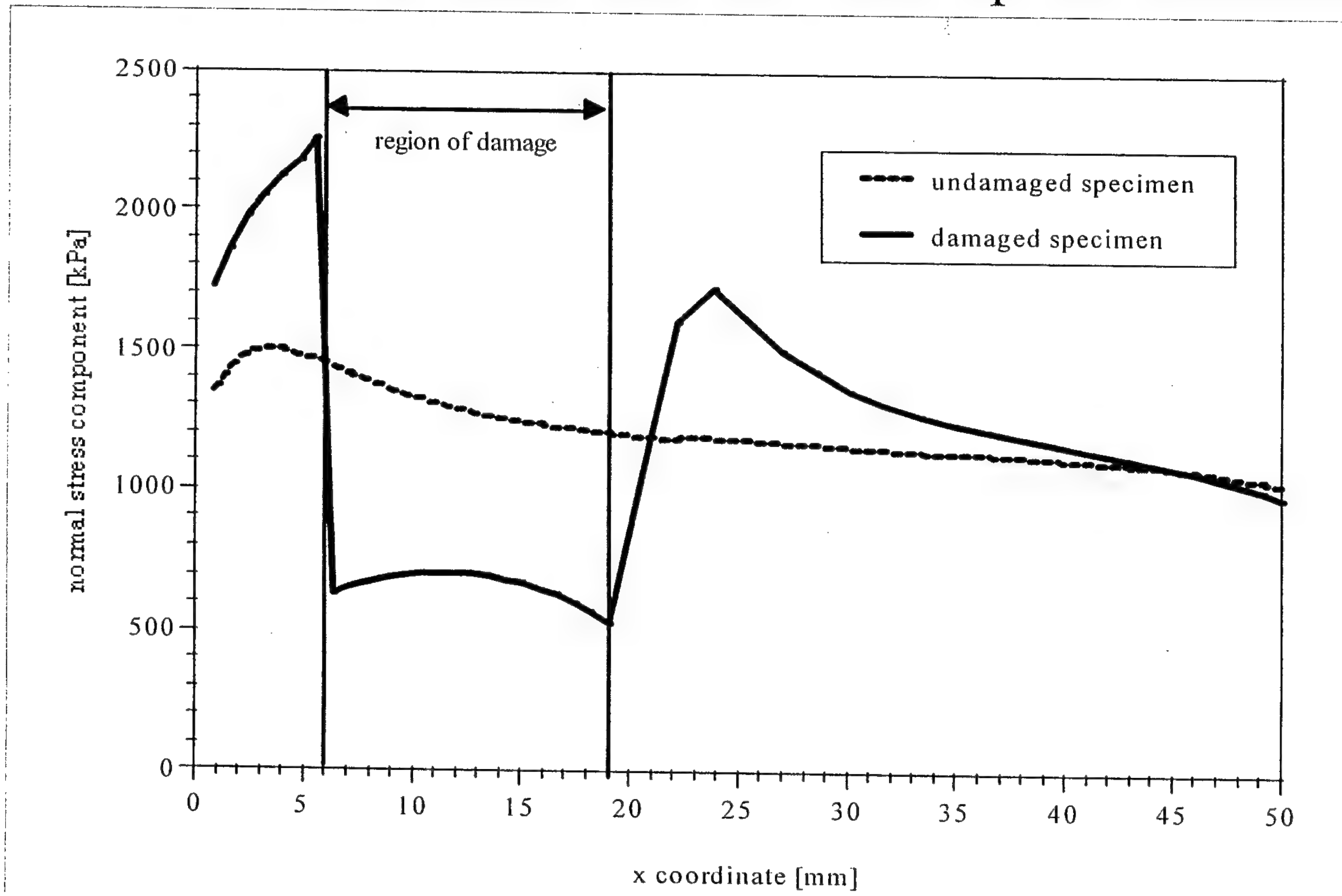
- Magnitude Effects
- Phase Angle Effects

Magnitude Effects - General Results

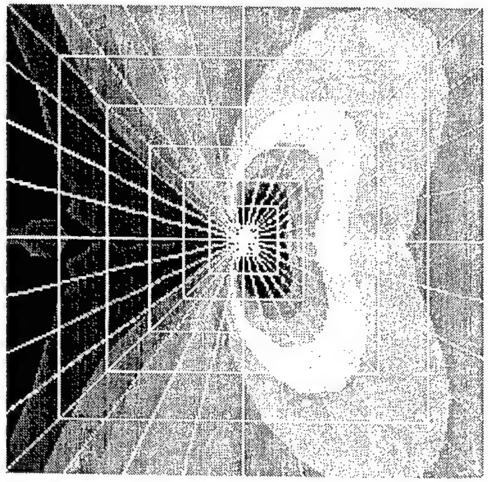
- The effect of the damage zone was to increase the magnitude of K
- The effects were small except for the largest of the damage zones
- For the large damage zone, $|K|$ was increased by about 20% with respect to the undamaged specimen results (in the top material, increases were from 17 to 24% depending on the loading angle)
- This effect was similar regardless of which material contained the damage
- The reason for the elevation is a "magnifying effect"

Magnitude Effects - Magnifying Effects

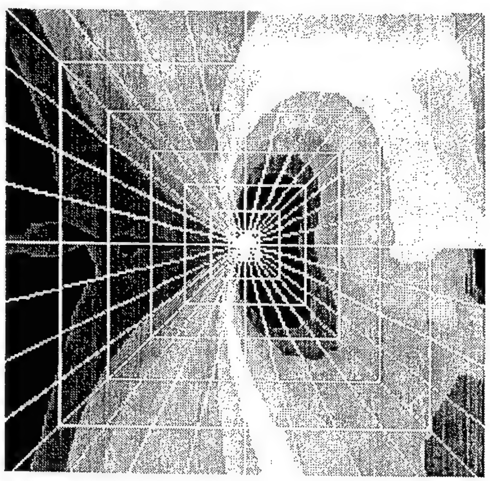
- Damage near the crack tip causes a redistribution of the loads so that the stresses near the crack tip are intensified



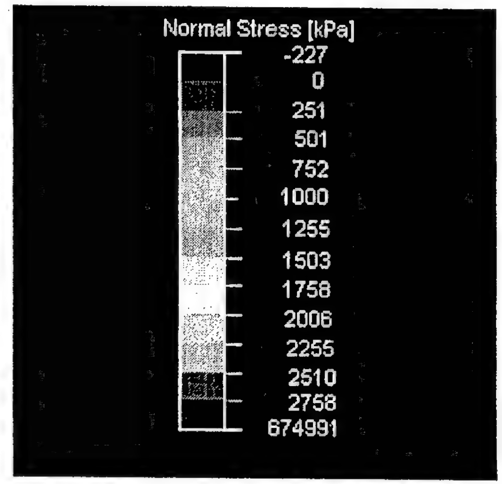
Magnitude Effects - Normal Stress Contours



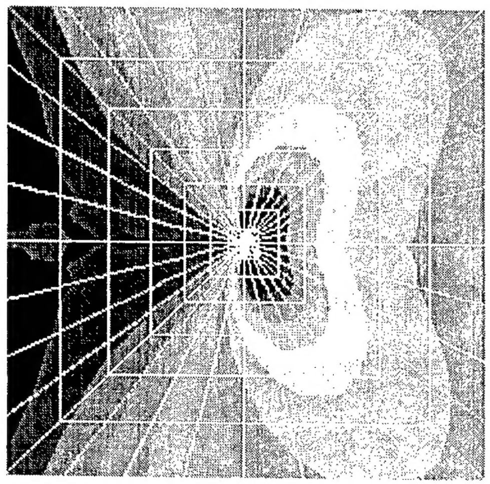
Undamaged Specimen with Vertical Loading



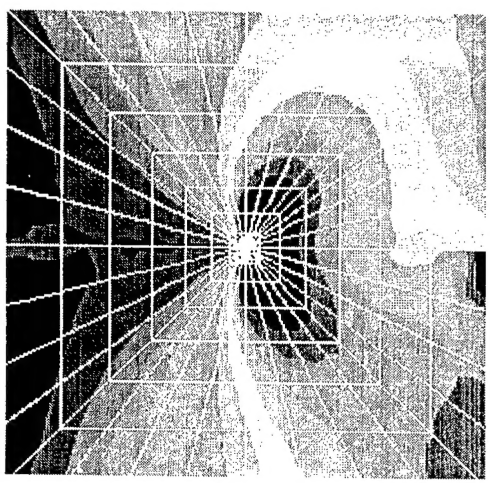
Specimen with Large Scale Damage in Lower Material and Vertical Loading



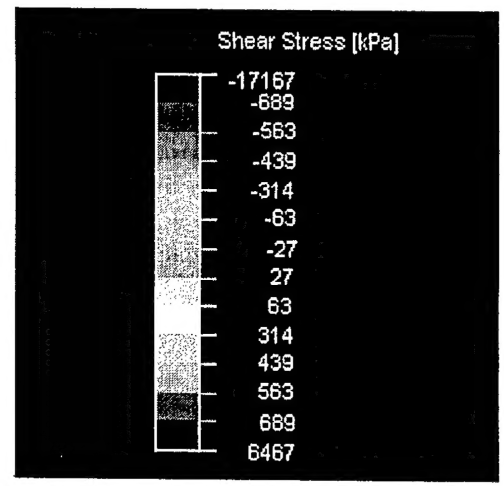
Magnitude Effects - Shear Stress Contours



Undamaged Specimen with Vertical Loading



Specimen with Large Scale Damage in Lower Material and Vertical Loading



Magnitude Effects - Specific Results

Percent Change in Magnitude of Stress Intensity Factor Compared with Results for Undamaged Specimen

L, size of damage zone [mm] \ Loading angle ω	0°	30°	60°	90°
Damage in material 1 (top material)				
3.175	1.5	1.3	1.2	1.2
6.350	5.9	5.0	4.7	4.6
12.700	24.4	19.0	17.8	17.0
Damage in material 2 (bottom material)				
3.175	1.0	0.4	9.2	0.1
6.350	4.4	1.7	1.1	0.7
12.700	19.5	10.0	8.0	6.5

Phase Angle Effects

Change in phase angle of stress intensity factor compared with results for undamaged specimen

L, size of damage zone [mm] \ Loading angle ω	0°	30°	60°	90°
Damage in material 1 (top material)				
3.175	0.28	0.16	0.44	0.06
6.350	0.97	0.50	0.32	0.05
12.700	2.15	1.59	0.19	0.26
Damage in material 2 (bottom material)				
3.175	0.26	0.08	0.08	0.08
6.350	0.96	0.31	0.17	0.24
12.700	2.43	0.63	0.08	0.76

- The effect of the damage zone was not significant.
- Since the "magnifying effect" affected the shear stress and normal stress components approximately equally, the phase angles were not affected by the introduction of damage, although the magnitudes were.

Conclusions

- The presence of damage near the tip of an interfacial crack redistributes the stresses so that the stresses are raised near the crack tip, resulting in a higher value for the magnitude of the complex stress intensity factor.
- The damage zones have less effect on the phase angle than the magnitude, however, because the normal and shear components are similarly affected.
- The size of the damage zone is a critical factor; small damage near the crack tip has a negligible effect but larger damage zone sizes can elevate the magnitude of the stress intensity factor by up to 24%.